Rocket Activity

Pop Can "Hero Engine"

Objective
To investigate Newton's third law of motion using thrust produced by falling water.

Description
Small student teams will construct water-propelled engines out of soft drink cans and investigate ways to increase the action-reaction thrust produced by water shooting out of holes punched in the can sides.

National Science Content Standards

Unifying Concepts and Processes
- Change, constancy, and measurement

Science as Inquiry
- Abilities necessary to do scientific inquiry

Physical Science
- Position and motion of objects
- Motions and forces

Science and Technology
- Understanding about science and technology

National Mathematics Content Standards
- Number and Operations
- Measurement
- Data Analysis and Probability

National Mathematics Process Standards
- Reasoning and Proof
- Communication
- Connections
- Representations

Materials
4 empty aluminum soft drink cans per team, with pull tabs intact
Carpenter's nails of different sizes (6,12, 16D, etc.)
String (about 50 cm)
Water tub (large plastic storage tub, small kiddy pool, sink, etc.)
Water
Towels
Rulers
Stickers or bright permanent marker

Management
Divide your students into small groups. Set up one or more water tubs around your classroom and fill the tubs with about 20 cm of water. Have no more than one or two teams test their engines at one time. Discuss the importance of keeping the water in the tubs. When engines are filled, they should not be raised any higher than the rim of the tub. This will keep water coming out of the holes from falling on the surrounding floor. Be sure to recycle the cans at the conclusion of the activity.

Tip Ask students to bring undented and washed soft drink cans from home. You will need at least three cans per student team.

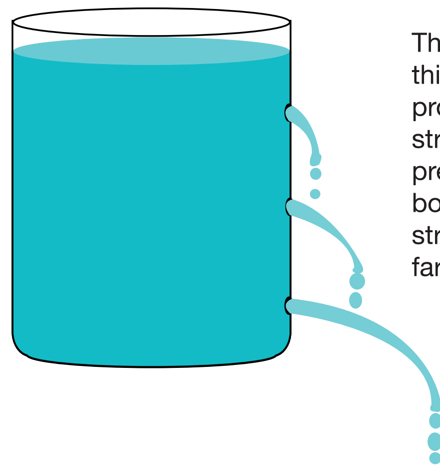
Background

This activity simulates the operation of the classic aleoliphile engine invented by Hero of Alexandria more than 2,000 years ago. (See page 2.) Hero's engine was a spinning copper sphere that was propelled by a thrust produced by a jet of steam. The engine was an early demonstration of the action-reaction principle (third law of motion) stated by Sir Isaac Newton 1,700 years later. (See page 4.) Steam, shooting out through two L-shaped holes, creates an action force that is accompanied by an equal reaction force in the opposite direction.

Hero's invention was not self-contained and therefore, not a true rocket device. Heat to generate the steam had to be applied externally. Rockets are completely self-contained.

In this activity, a Hero engine-like device is created by the students. Holes are punched in the side of a soft drink can. The holes are angled pinwheel fashion. A string, tied to the pull tab, supports the can and permits it to rotate. The can is immersed in water and pulled out. Gravity draws the water through the angled holes, and streams shoot out in either a clockwise or counterclockwise direction. The streams produce an action force that is accompanied by a reaction force. The can spins in the opposite direction.

There are many potential variables with the Pop Can Hero engine. Hole size, hole angle, number of holes, and the placement of the hole above the base of the can all affect the thrust produced. The most significant of these variables is the hole placement. The greatest thrust occurs when the holes are punched just above the bottom of the can. This is a gravity effect. The strength of the water stream (thrust) is based on the pressure. Water pressure in a container is the greatest at the bottom. The pressure at the top of the water in the container is zero (ignoring air pressure in this example). Water dribbles out of a hole near the top of the column. The water stream gets stronger the closer the hole is to the container bottom. Thrust stops when water drains out to the level of the holes. Holes at the bottom of the container produce thrust for a longer time. However, the magnitude of the thrust diminishes as the water column lowers (pressure drops with column height).



The three holes in this container each produce a water stream. Greater pressure at the bottom makes the stream shoot out farther.

The effects of the other variables are many. For example, more holes means more water streams out of the can, but the water drains from the can more quickly. Large holes drain water more quickly than small holes. Holes angled in different directions counteract each other. Holes that are not angled produce water streams that leave the can perpendicular and no rotation occurs. (The object is to have students discover the effects of the different variables themselves.)

Procedure Making the Pop Can "Hero Engine"

1. Divide your students into small teams of two or three members.
2. Demonstrate the procedure for punching holes in the cans. The idea is to punch the hole without crushing the can sides. Place the nail point near the bottom rim of the can. Apply pressure with the nail, turning it, if necessary, to make the hole.
3. When the hole is punched, push the nail head to the right or to the left. This will angle the hole so that water will stream out on a tangent to produce thrust.

tangent to produce thrust.
4. Rotate the can 1/4 turn and punch a second hole. Again angle the hole (in the same direction as before).
5. Repeat the procedures two more times to make four holes in total. (Cans may have different number of holes.)
6. Tie a string to the pop top.
7. Immerse the can in the tub of water.
8. When the can is full of water. Pull it out by the string and observe the rotational motion.

Procedure: Student Team Experiment
1. Provide each team with copies of the “Pop Can Hero Engine” experiment sheet.
2. Review the instructions on the page and discuss the objective (“Design an experiment to find a way to increase the number of rotations the Pop Can Hero Engine makes.”)
3. Make a list of student ideas for variables to test - hole size, number of holes, etc. Discuss the importance of changing only one thing at a time. The first Hero engine they create will serve as the baseline experiment. The second and third engines will vary just one thing. (E.g. Can 1 - medium size holes, Can 2 - smaller holes, Can 3 - larger holes)
5. Discuss ideas for keeping track of the number of rotations the cans make. (Place a large bright mark on one side, etc.)
4. Give teams time to pick their experiment, devise their hypothesis, and to write the procedures they will follow on their experiment page.
5. Distribute the materials to the teams and have them begin their investigation.

Discussion:
• *What provides the force that causes the cans to rotate?*
Actually, there are a combination of factors that contribute to the force that causes the cans to rotate. The most important is the force of gravity. It attracts the water in the can and causes it to stream out the holes. The shape of the holes directs the water streams. The diameter of the holes determines how fast the water streams out, etc.

Tip: Make sure the nails used for punching holes have good points on them. They do not have to be needle sharp, just not blunt.

• *Which of Newton’s laws of motion explains why the can rotates in the opposite direction from the direction of the water streams?*
Newton’s Third Law of Motion
• *Based on the results of the individual team experiments, what could you do to maximize the number of rotations of the Pop Can Hero Engines?*
Individual answers: combine best hole size with the right number of holes, best placement, etc.

Assessment

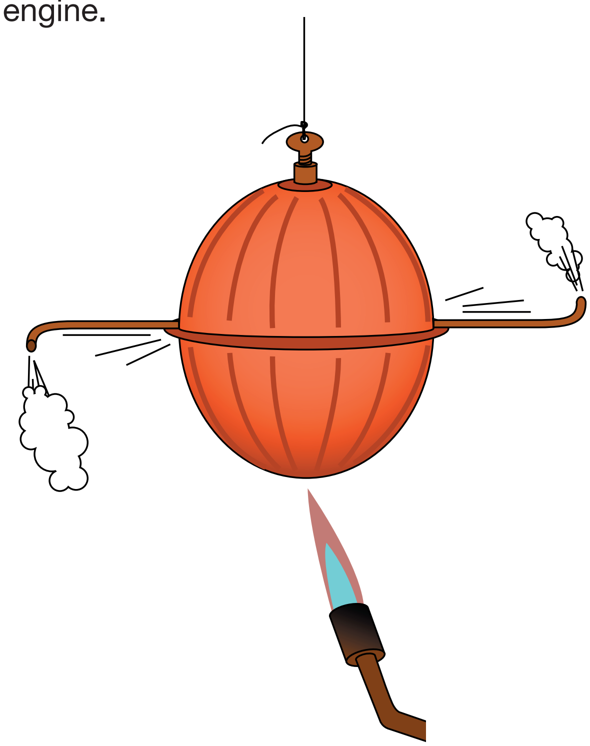
- Ask teams to state their experiment hypotheses, explain their procedures, and present their results. Make a list of the different ways one can increase the number of rotations the Hero engine makes.
- Have teams submit their completed data sheet with their written conclusion based on their results.

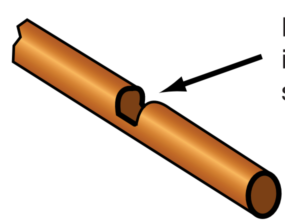
Extensions

- Construct an actual steam-powered hero engine and use it as a demonstration device. Although not difficult to construct, the engine will require some basic construction skills, principally soldering. You will need the following materials:

  - Copper toilet tank float (available from plumbing supply stores and from on-line plumbing supply stores - search “copper toilet tank floats.”
  - 12” copper tube, 3/16” diameter (from hobby shops)
  - Thumbscrew to fit threads for float arm attachment
  - Metal file
  - 3/16” drill
  - solder
  - propane torch
  - pliers
  - string
  - water
  - eye protection

1. File a notch in the center of the tube. Do not file all the way through. In Instruction 3, the tube will be inserted completely through the sphere. This supports the tube while it is being soldered. (See diagram to the right.)
2. Drill 3/16th” holes through opposite sides of the float just above the “equator” joint.
3. Insert the tube through the holes. Lightly heat the place where the tubes contact the sphere. Touch solder to the contact point to seal the tube to the float.
4. Apply heat to soften the opposite ends of the tube until they bend easily. Using pliers to grasp the ends, bend the tube ends into an L shape. Be careful not to overheat or bend too forcefully, or the tube may flatten on the bend.
5. Drill through the center of the threads for the attachment point for the float arm. This will open a water-filling hole into the float.
6. Drill a hole through the flat side of the thumb screw to permit tying of the string.
7. Pour about 30 milliliters of water (about 1 tablespoon) into the float through the filling hole.
8. Thread the thumbscrew into the hole and attach the string.
9. Suspend the engine from above and gently heat the bottom of the engine with a torch. Be sure to wear eye protection. When the water boils, steam will be produced that will jet out of the two nozzles and propel the engine.





Filing produces an opening in the tube through which the steam can pass.

Tip Before using your steam Hero engine, confirm the tubes are not blocked by blowing through them. If air comes out the opposite tube, the engine is safe to use.

Pop Can Hero Engine

Team Member Names:

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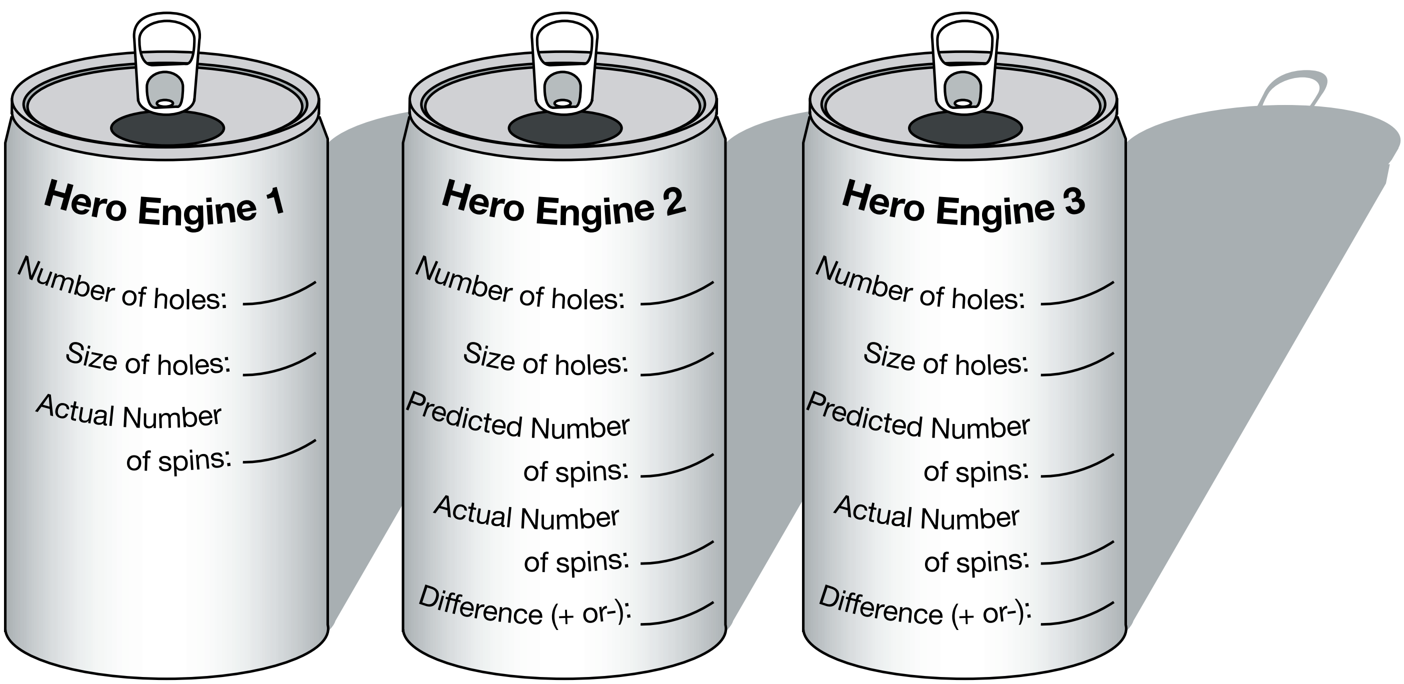
Design an experiment to find a way to increase the number of rotations the Pop Can Hero Engine makes.

Write your experiment hypothesis below.

Briefly explain your experiment procedures below.



Based on your results, was your hypothesis correct?

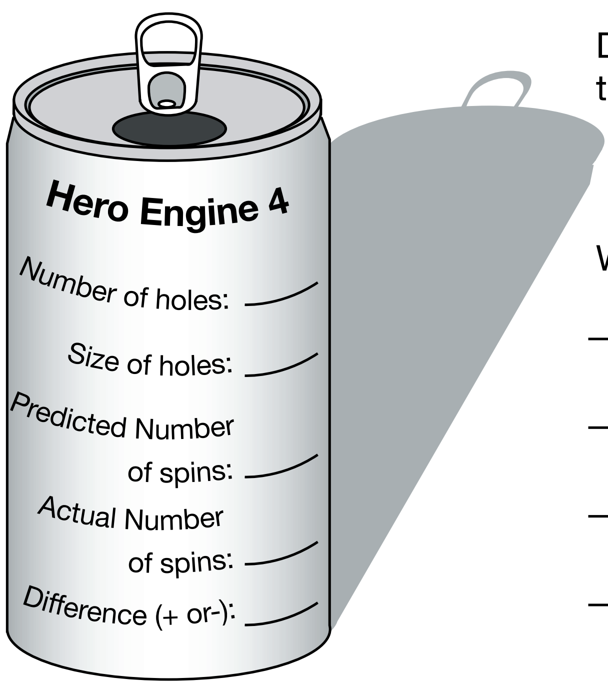
Why?

Pop Can Hero Engine

Design and build a new Hero Engine that maximizes rotation rate.

What things did you learn from your experiment and the experiments of others for increasing the Hero engine rotation rate?

Briefly describe your new Hero Engine (hole size, number of holes, placement, etc.)



Did your new Hero engine out-perform the original engines you built?

Why or why not?

What did you learn about Newton's laws of motion by building and testing Hero engines?